This study sought to determine the amount of power used by a typical household for the purposes of home entertainment. As more and more people choose to purchase more elaborate home entertainment equipment, the per-household power draw of such devices will only continue to increase.

A measure-based analysis of domestic power consumption due to home entertainment devices

by Albe Bredekamp, Cape Peninsula University of Technology

How much of the typical South African households' power consumption is due to the use of home entertainment devices? For the purposes of this study individual measurements of the power consumption of a variety of home entertainment devices was made. Voltage and current waveforms were also recorded. Three models were then created grouping different configurations of devices together. For each group or model, the total current was synthesised and then subjected to a Fast Fourier Transform to investigate the harmonic content. The total power consumed by the combination of devices was also calculated.

Research statement

Studies performed up till now have only focused on the power consumption of specific devices such as digital set-top boxes and television sets. Many papers have been published on attempts to reduce the on-mode or standby power consumption of specific home entertainment devices.

This study will seek to determine the proportion of a typical households' energy consumption that can be attributed to home entertainment, as well as the effect that home entertainment equipment have on power quality.

The power consumption of selected home entertainment devices will be measured and a model created of a home entertainment installation. For the purpose of this paper it will be convenient for the reader to imagine all the home entertainment components being installed together in a cabinet. The power draw and harmonic characteristics of the "cabinet" was then modelled.

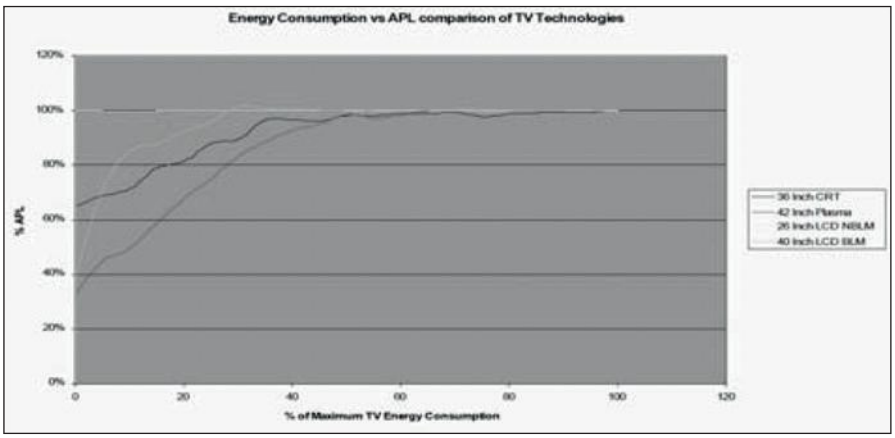

Fig. 1: Comparison of differing TV technology energy consumption characteristics.

Background

Since the introduction of television into South Africa in 1976, television has entered every aspect of our lives. It has become the primary form of home entertainment for many South Africans. The first colour television sets in South Africa were quite expensive, making for a slow initial uptake. Later, as many more households started to purchase television sets this new load on the power grid started to become more prominent.

With the availability of the first affordable video recorders on the local market during the early eighties, consumers were now for the first time able to rent movies and view them in their own homes.

When MNET started their first broadcasts in 1986, South Africans were first introduced to the set-top box. A set-top box is a device used to convert from one type of signal to another. In the case of the MNET set top box (more commonly called a decoder) the conversion was made from a scrambled to a de-scrambled signal. For many South Africans at the time MNET was considered a luxury. As such, uptake was slow and the effect of the new power

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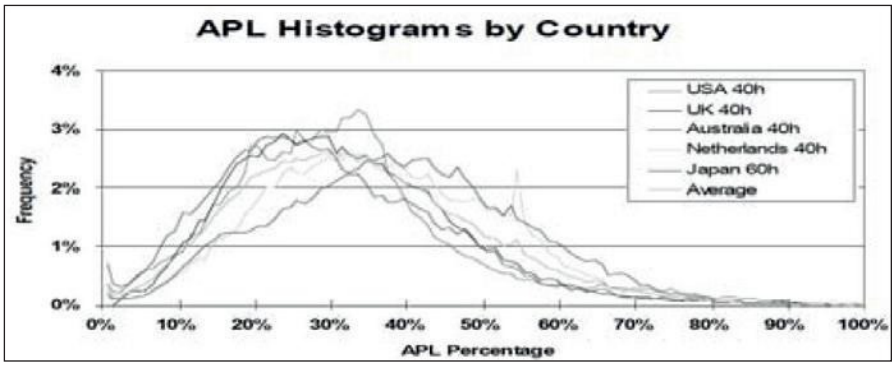

Fig. 2: APLs for different countries.

demand from set-top boxes was spread over many years.

Digital satellite television

Digital satellite television was first introduced to South Africa by Multichoice in 1992. Once again this new technology was considered a luxury. Satellite receivers were expensive and as such uptake was also slow. Once again the new demand from yet another set-top box was spread over many years. Multichoice reached 1,5-million subscribers in November 2007. From 1992 to 2007 the extra load on the national grid from DSTV decoders went from 0 W to approximately 27 MW (assuming 18 W per decoder, based on 2004 measurements). This additional load appeared gradually over 15 years.

Digital terrestrial television

South Africa is poised to make the transition from an analogue terrestrial television system to a fully digital terrestrial television system. The reasons are both economical and technological. Analogue transmitters use more power and bandwidth. Many of the analogue transmitters in South Africa also date from the 1970s and spare parts are becoming difficult to source. There are approximately 5,2-million television sets in South Africa. Assuming that current DSTV subscribers would have no interest in purchasing a new set-top box for terrestrial digital television, this still leaves 3,7-million television viewers who have to make the switch to digital by April 2013 or face having no analogue signal to receive.

If one set-top box uses 10 W (based on typical consumption of similar boxes) a new load of 37 MW can appear on the national grid in the span of only 3 years. The recent launch of TopTV shows how quickly a new national load due to set-top boxes can appear in a short time. TopTV launched in South Africa on 1 May 2010. Within one day 50 000 decoders were sold and after 3 months over 120 000.

Again, if we assume 10 W power consumption per decoder, a new load of over 1,2 MW has appeared on the grid in only 3 months.

Currently, most people own a traditional cathode-ray tube (CRT) based television with 480 lines of vertical resolution. They have a UHF antenna receiving an analogue television signal from terrestrial transmitters and/or a satellite receiver receiving a digital television signal from a satellite.

In the near future, viewers with traditional analogue televisions will be required to purchase a converter box to convert the digital terrestrial television signal to an analogue signal suitable for display by their television.

Given that there are over 5-million television sets in South Africa, the addition of millions of new power draws from converter boxes alone will be significant.

During the final stages of digital television migration, the consumer will have purchased a new liquid crystal display (LCD) or plasma TV with a digital tuner. The converter box for the UHF antenna is no longer needed. Although the one converter box has now been eliminated, the television set potentially consumes more power than the set it replaces. The consumer may now also have decided to add a DVD player with full surround-sound. Add video gaming consoles to the equation and people are spending more time being entertained at home now than they ever did in the past.

Power quality and energy consumption

With the explosion of electronic media such as the internet in the 1990s and the wide adoption of new home entertainment media such as DVDs, Plasma/LCD televisions and surround-sound since the beginning of the 21st century, the home energy usage landscape has changed considerably from that of 1975. According to Samotyj, M.J. Mielczarski and W. Wasiluk-Hassa, M.M. ITIC (Electric power for the digital age, 2003), modern digital home entertainment equipment demands power of high quality from the grid. The technology now exists to get a full high definition movie theatre experience, even in 3D, in your own home.

LCD televisions have almost completely displaced CRT televisions due to their compact design and superior picture quality. Almost all the television sets currently on display in a typical electronics store are LCD based. All LCD and plasma sets offer a vertical resolution of at least 768 lines.

All CRT televisions have a native vertical resolution of 480 lines.

Both in South Africa and elsewhere in the world electric power utilities are constantly striving to enhance their level of service to their customers while at the same time minimising their impact on the environment. In order to achieve these goals utilities need to have access to accurate information relating to how and when consumers are using energy as well as how much they use. This information is vital for grid capacity and power plant construction planning. Utilities need to also provide power of high quality which is stable in voltage and frequency, but also free of excessive harmonics.

According to the South African Advertising Research Foundation, South Africans watch three to four hours of television per day. This in turn means that the typical South African television set is in standby mode for 20 out of 24 hours.

According to Shuma-Iwisi et al. the bulk of television sets in use are less than 10 years old. This means that an accurate national standby power consumption figure for television sets can be calculated using consumption data for different models from 1999 – 2009.

The bulk of sets measured by the author in 2004 used less than 2 W of power during standby, with a few sets using up to 11 W. If 5,2-million television sets each draws 2 W during standby, that is a load of 10,4 MW that could potentially be reduced or eliminated.

It is however not sufficient to simply manage the standby power consumption of television sets. Traditional CRT based television sets use 80 – 100 W of power during normal operation. Newer plasma screen sets can use up to twice as much. With CRTs quickly becoming obsolete,

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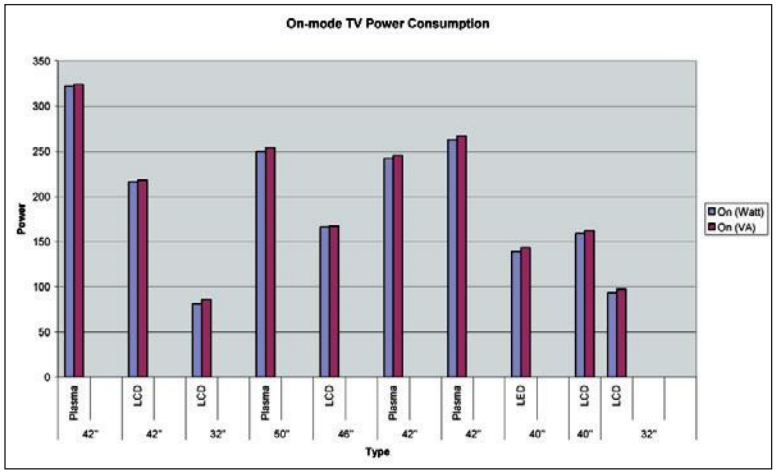

Fig. 3: The power consumption in Watt and VA of new television sets in on-mode.

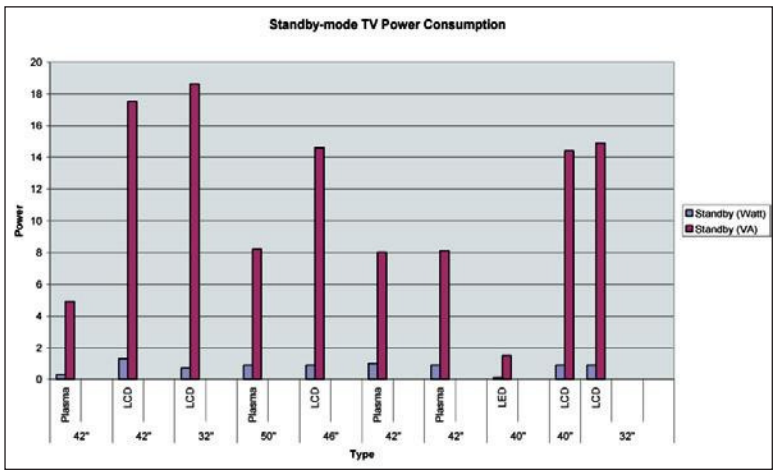

Fig. 4: The power consumption in Watt and VA of new television sets in standby-mode.

consumers will be replacing their CRT based television sets with newer plasma screen or LCD based sets. If newer sets use more electricity than the sets they replace, the peak demand from television sets will increase. The ideal situation would be for the replacement sets to use less electricity than the sets they replace.

Testing

Before measurements of the power consumption of television sets can be performed, a testing methodology has to be established that will produce the most accurate and relevant results. Jones and Harrison discussed the need for an improved testing methodology for television sets in 2007, given the growth in the use of LCD and Plasma based sets. Their goal was to develop a test method to better reflect the way sets are actually used.

Average picture level

When measuring the power consumption of a television set the average picture level (APL) must be taken into account. The reason is that the power consumption of television sets varies with picture brightness. Dr Larry Weber delivered a paper in San Francisco in 2005 that highlighted the inadequacy of existing test patterns to adequately simulate the APLs that are inherent in video signals being displayed on televisions.

Fig. 1 shows that the power consumption of a 26-inch LCD panel with no back-light modulation (NBLM) remained constant for all APLs while the power consumption of a 42-inch plasma, 36-inch CRT and 40-inch LCD television with backlight modulation (BLM) varied with APL. From Fig. 1 it is also evident that APLs above 40% have very little effect on power consumption. Studies in the USA, UK, Australia, Netherlands and Japan have produced the histogram of Fig. 2. From Fig. 2 it is interesting to note that the APLs for all the countries are very similar. It is therefore reasonable to assume that South African APLs will be similar. Fig. 2 shows few pictures in excess of 50% with the average of the samples varying from 30% (Australia) to 35% (Japan). Since it can be shown that most television pictures have an APL below 50%, and this being the region where television energy consumption has its greatest variation, it is vital to consider APL as a factor when measuring television power consumption.

For the purposes of this paper the On Mode and standby power consumption of televisions will be measured. For the On Mode measurement the JEITA and IEC 62087 measurement methods are relevant.

IEC 62087

The IEC makes a DVD and Blu-Ray disc set available that is used to provide standard pictures for display on a television while power consumption measurements are made. "The clips include fast-moving action, wildlife footage, a range of studio-based coverage, and even animated cartoons."

For the purposes of this paper we are interested in the power consumption of a television set at a specific and static APL which requires the use of a static test pattern. The IEC 62087 standard uses a three bar black and white pattern for the measurement of "On Mode" power. This pattern has an APL of 50%. It has previously been shown that televisions at this APL level will show a power consumption of 100%. To more realistically test the power consumption of television sets, the revised IEC test method include natural moving image test clips that produce more measurements of power consumption.

JEITA

The other standard relevant to the measurements performed in this research is the JEITA standard that uses four patterns, 0% Black (black display), 100% White Raster (brightest display), three bar Black and White (50% APL) and colour bars (50% APL). The results of the measurements are then averaged according to the following formula:

$$((P_w + P_b)/2 + P_c + P_t)/3$$

where

P_w = power measured at 100% white

P_b = power measured at 0% black

P_c = power measured with colour bars

P_t = power measured with three bars

The JEITA method effectively gives a weighting of 83,25 to 100% power consumption when in fact very few pictures ever reach this level and 16,75% to the power consumed at an APL of 0% when less than 1% of pictures are ever at this level. Jones and Harrison argued that the IEC 62087 and JEITA standards for measuring power consumption in television sets are inadequate and unrealistic. It was shown that in addition to the power consumption of the pictures being displayed, the test method should also consider the contribution to power consumption of the following factors:

- Audio – How much amplification is provided for audio and what are the typical listening levels?
- Digital tuners – These tuners often stay active during standby in order to download updates to television firmware.
- Standby power – How much power does the set consume during standby mode?
- Energy saving features and settings – What energy saving features are available and are they enabled by default?

Limitations of the tests conducted

For the purposes of this research the power consumption of new television sets on display at an electronics store was measured. As limited facilities for introducing one's own test images was available and suitable test material could not be readily obtained it was decided to test all sets under the following conditions:

- All power saving features were bypassed
- All televisions were set to display a snow pattern. A snow pattern on a television set has a random distribution of peak white and black pixels.
- Controls for brightness, contrast and colour saturation were not adjusted from the settings as set up by sales staff in the store. It was assumed that all sets were adjusted for a comfortable brightness and contrast level. It was believed that this would be more representative of actual viewing APLs.
- The sound on all televisions was muted during testing

Ampere	% of fundamental	Phase angle Ψ	Frequency	Harmonic number
1,538816674		20,35585931	48,828125	1
0,014619263	1,0%	-178,8022684	97,65625	2
0,548918381	35,7%	72,15750069	146,484375	3
0,043213667	2,8%	93,7432354	195,3125	4
0,052914915	3,4%	41,18198303	244,140625	5
0,003685877	0,2%	53,39309164	292,96875	6
0,025568106	1,7%	-61,84593444	341,796875	7

Table 1: Results of the Fourier analysis in Excel, on mode.

Testing methodology

The accuracy of the models presented in this study in turn relies on the accuracy of the quoted consumption figures of appliances.

Appliance producers can sometimes be optimistic with their quoted power consumption figures. It is therefore important to confirm the consumption figures of appliances. This can be accomplished by direct measurements of the power consumed by an appliance while in normal operation and standby modes. For the purposes of this research, the power consumption of an appliance was measured at the power socket outlet (pso).

Measurements were also conducted of voltage and current waveform shapes for later analysis.

New appliances were measured at Tafelberg Furnishers in Somerset West. Existing appliances were also measured in the authors' home.

Methodology

To perform measurements of the power consumption of appliances the following equipment was chosen:

- Fluke 43 power quality analyser
- Fluke 80i-110s AC/DC current probe

To measure the power consumption of a device, a piece of 2-core cable was placed between the device to be measured and the power socket outlet. Inserted into one of the conductors of the 2-core cable is a 10-turn toroidal coil. During measurements the coils were fanned. The jaws of the current probe were clamped over the coil. For power measurements the Fluke 43 also requires a voltage pickup. From Fig. 3 it is evident that real and apparent power components are very similar. This is due to the active PFC employed by modern LCD and Plasma television sets. This finding is in line with the European Norm EN61000-3-2, requiring devices consuming more than 75 W to employ PFC. From Fig. 4 it can be seen that while the real power in standby mode is extremely low, the apparent power in standby mode is consistently much higher. This means that while less energy (Joules/second) is used by television sets in standby mode their apparent power is still high. This also means that the reduction in standby consumption does not equate to a lowered effect on the

	Model 1		Model 2		Model 3	
	On-mode	Standby	On-mode	Standby	On-mode	Standby
Total power (W)	243,03	5,772	332,17	6,161	99,84	1,761
Overall power factor	0,94	0,35	0,98	0,57	0,93	0,1
Amplitude of 3rd and 5th harmonic relative to fundamental	3rd=35,7% 5th=3,4%	3rd=15,4 5th=14,7%	3rd=7,6% 5th=11,3%	3rd=30,8% 5th=21%	3rd=19,7% 5th=5,8%	3rd=9,7% 5th=13,1%
Devices	Samsung 46" LCD TV, NAD DVD player, NAD AV Receiver, NAD CD Receiver		Samsung 50" Plasma TV, NAD DVD player, NAD AV reciever, NAD CD Reciever		SAMSUNG 32" LCD TV, NAD DVD player T515	

Table 2: Summary of results from models 1, 2 and 3.

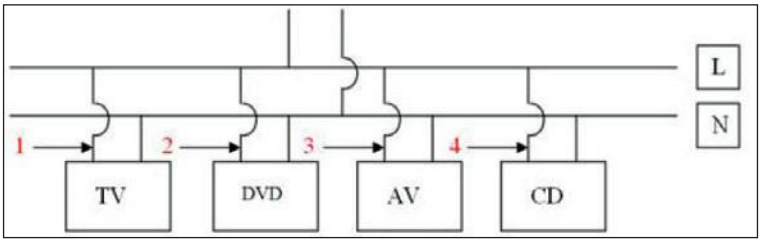

Fig. 5: Bus view of the devices for model 1.

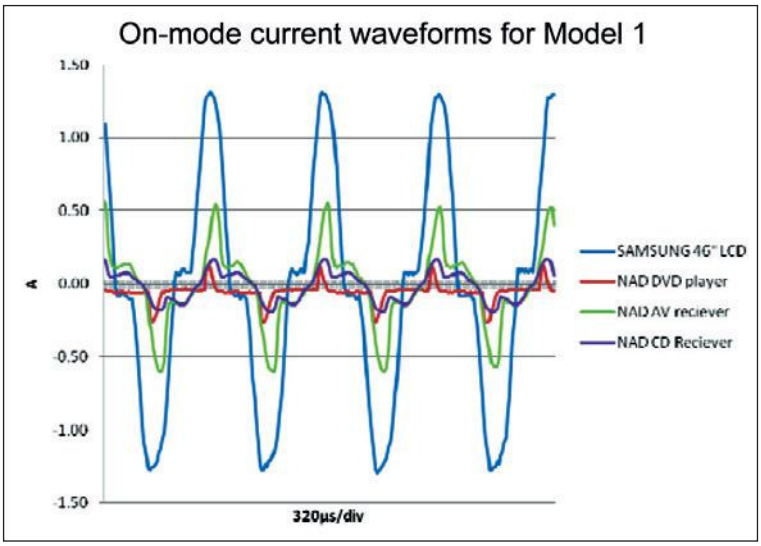

Fig. 6: Current waveforms for devices in model 1 (on-mode).

grid. It is possible that millions of devices in standby mode can still have a marked effect on power quality due to harmonics.

From Fig. 4 it is also evident that the real standby power consumption of modern LCD and plasma sets is consistently below or very near 1 W. The average standby power consumption of a television in 2004 was 3,6 W compared with 0,8 W in 2009. A reduction in standby power consumption of 78% was achieved in 5 years. A potential problem surfaces though when one compares the on mode power consumption of older CRT sets and newer LCD/Plasma sets. While the average on mode power consumption of a CRT TV is about 90 W that of an LCD/Plasma set is about 190 W. An increase of over 211% was observed. Energy Star allows for an increase in on mode power consumption between older CRT based (480 line) sets and newer LCD/Plasma (768 or 1080) line sets. While the average maximum allowed on mode power consumption of 480 line sets is 120 W, it is 220 W for 768/1080 line sets. An increase of 183% was observed. This means that most of the increase in on mode energy consumption is due to the change in display technology. The observed increase in on-mode power consumption of LCD/Plasma sets as compared to CRT sets was more than that allowed by Energy Star. For model 1 a high-end home entertainment set-up was modelled containing the following items:

- Samsung 46" LCD
- NAD DVD player
- NAD AV receiver
- NAD CD receiver

Fig. 5 shows a bus view of the devices for model 1.

The current at locations 1, 2, 3 and 4 was measured. The voltage at locations 1, 2, 3 and 4 was also measured.

Since four separate voltage and current measurements were taken originally, four different voltage and current waveforms are obtained. The current waveforms are shown in Fig. 6.

	Diagonal inches
CRT	21,4
LCD	30,1
Plasma	44,8

Table 3: Average diagonal screen size in 2009.

	Million	Percentage of total
CRT	102,9	51,1
LCD	82,9	41,2
Plasma	15,3	7,6

Table 4: Market trends for television sets in 2009.

Fig. 6 shows the individual current waveforms for each device present in model 1. It can be seen that the largest contributor to the total current draw is the 46" LCD television (blue). To obtain the graph in Fig. 7 the waveforms of Fig. 6 were added together by calculating the instantaneous amplitude of the sum of the waveforms at each sampling point. Fig. 7 shows the resultant waveform as synthesised from the waveforms in Fig. 6.

It can be seen from Fig. 7 that the current waveform is largely symmetrical, which would indicate the presence of mostly odd harmonics. This finding is verified in Fig. 8. Fig. 7 represents a complex waveform and may be represented by equation 2:

The process of harmonic analysis is then a case of finding the coefficients Y_{1m}, Y_{2m} …etc., and the phase angles Ψ_1, Ψ_2 … etc. Fourier analysis of the waveform in Fig. 7 will allow us to determine the aforementioned coefficients and phase angles. Table 1 details the results of the harmonic analysis in Excel. For each harmonic the phase angle Ψ is shown.

Each harmonic is also represented as a

$$y = Y_{1m}\sin(wt + \Psi_1) + Y_{2m}\sin(wt + \Psi_2) + \cdots$$

percentage of the 1st harmonic. Notice that the 3rd harmonic is at 35% of the fundamental.

The same process was used to model two more configurations of entertainment devices. The results are summarised in table 2. Table 2 shows a summary of the results from models 1, 2 and 3. The only difference between model 1 and 2 is the type of television set, a 46" LCD and 50" plasma respectively. In model 2 the Plasma television set alone was responsible for an increase in on mode consumption of 89 W. Overall power factor remained above 0,9 for all models during on mode. All models showed a significantly poorer power factor during standby-mode.

Television set consumption analysis

Before any further analysis of the measured power consumption due to home entertainment devices can be undertaken, it must be determined what size plasma/LCD television consumers will choose to replace their existing CRT based sets with. Three worst case scenarios were modelled:

- Model 1, full-featured home entertainment with large screen LCD TV
- Model 2, full-featured home

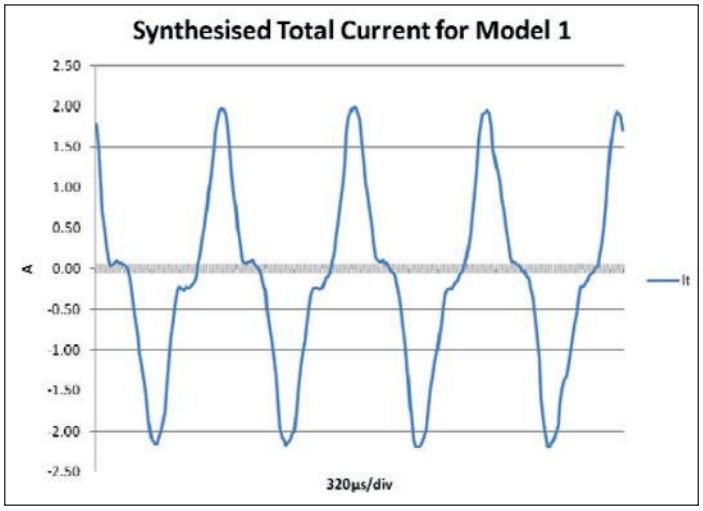

Fig. 7: Total current waveform for model 1.

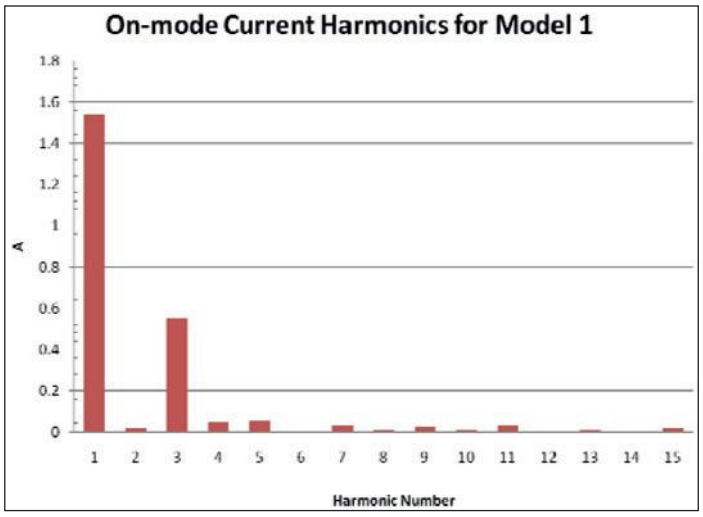

Fig. 8: Harmonic spectrum for model 1.

	Number of sets in millions	Typical size in inches
CRT	2,6572	21,4
LCD	2,1424	30,1
Plasma	0,4004	44,8
Total	5,2	-

Table 5: Estimated number of sets in South Africa by screen size..

entertainment with large screen Plasma TV

- Model 3, basic home entertainment with medium screen LCD TV

The motivation behind why a consumer would choose one type of set over another is varied and complex. Certain assumptions would therefore need to be made. These are:

- The replacement set has to fit in the same space as the old set
- The replacement set must have the same apparent image size as the set it replaces.

Referring to Table 2, it can be seen that in model 2 the relative amplitudes of the 3rd and 5th harmonics both increased during standby while in models 1 and 3, 3rd harmonics decreased and 5th harmonics increased.

The range of power consumption due to home entertainment for a typical household is therefore 100 to 350 W. Models 1 and 3 only had a significant 3rd harmonic in the on mode while model 2 had almost no significant harmonics. Models 1 and 3 had no significant harmonics in standby mode, but model 2 had significant even and odd harmonics. While models 1 and 3 do not indicate any power quality issues except for a significant 3rd harmonic, the presence of significant odd and even harmonics during standby in model 2 can be problematic for power quality if many such configurations are present in a specific area.

- Consumers would prefer a new set with the same image area as the older set
- Consumers equate screen size with status

Normally it would be simple to say that a consumer would replace an existing 64 cm set with a new 64 cm set.

A problem arises since new television sets have a 16:9 image aspect ratio whereas older CRT sets have a 4:3 aspect ratio. To specify the image size of a particular television, the diagonal distance between the corners of the image is measured. If consumers were to choose a replacement for a 74 cm CRT TV according to screen area they would need to purchase a 32" 16:9 aspect ratio set. In this case there would be a reduction in power consumption as the replacement sets all use less than or equal amounts of power than the older CRT sets they replace. A typical 32 inch set uses 27 W less than the CRT set it replaces.

It is however unlikely that the typical consumer will be this logical with their purchasing choices opting rather for a "bang for buck" approach. This means that most consumers will choose to get the largest screen possible for the least amount of money. A study performed by Jones and Harrison supports the assumption that consumers are choosing sets with larger screens.

Fig. 9 shows the cost per inch of screen size for both LCD and plasma television sets from a typical electronics store. From the diagram it can be seen that there exists an area above 46 inches where LCD panels' cost/inch suddenly goes up. It would therefore be reasonable to assume that most consumers would choose an LCD set between 42 and 47 inches. The situation is different for plasma sets. From Fig. 9 it can be seen that the cost/inch of screen size for plasma sets is much less with no sudden increase evident above 47 inches. This means consumers are more likely to buy large screen plasma sets than large screen LCD sets if price is the prime factor driving their decision. The choice of available screen sizes for plasma sets appear to be limited to 42 and 50 inches.

The bulk of the energy consumed by an LCD TV set is used for the cold cathode neon back light. Right now display manufacturers are attempting to reduce the on mode power consumption of their sets by using new, novel and more efficient back lighting technologies such

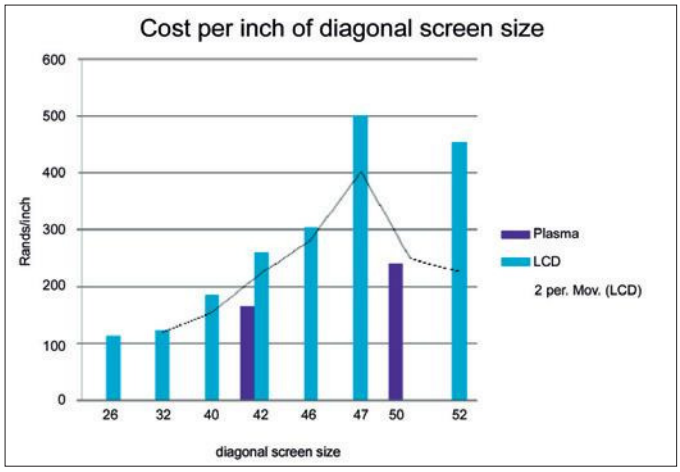

Fig. 9: Relative cost per inch of screen size for Plasma and LCD based television sets.

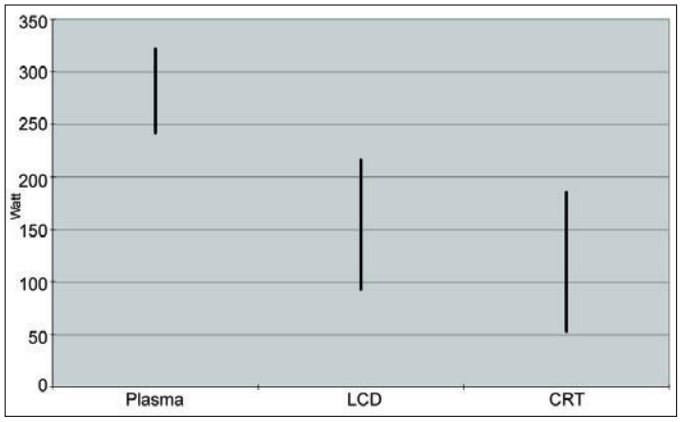

Fig. 10: Range of measured on-mode power consumption for LCD, Plasma and CRT television sets, all sizes.

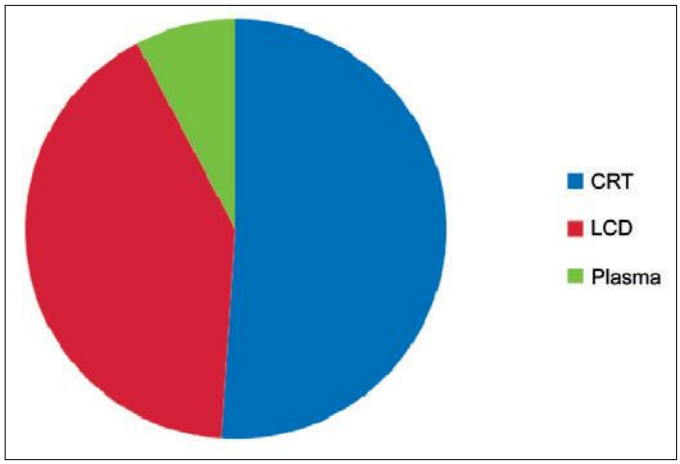

Fig. 11: Relative distribution of CRT, LCD and Plasma television sets in the world.

as LEDs and OLEDs. Any technology improves with time and so it is reasonable to say that the energy efficiency of LCD/Plasma displays will only continue to drop.

Power consumption due to television sets alone

The previous sections showed that the bulk of the power consumption in models 1, 2 and 3 are due to the television set. Fig. 10 shows the range of measured power consumption for different types of television sets. It is again evident from Fig. 10 that plasma sets use significantly more power than either LCD or CRT sets.

It has been stated before that according to the South African Advertising Research Foundation, South Africans watch 3 to 4 hours of television per day. According to Harrison and Jones the average diagonal screen sizes as used by consumers are as shown in table 3.

This data confirm the observations of Fig. 9, showing that when it comes to truly large screens, consumers would opt for a plasma screen due to the favourable cost/inch of screen size.

Also according to Harrison and Jones the world wide TV market trend is as shown in table 4, where half of the TV sets in use in the world are still CRT based with the other half shared between LCD and Plasma.

It has been stated earlier that there are approximately 5,2-million television sets in South Africa. From Tables 3 and 4 a model of a typical household can be constructed for South Africa if it is assumed that television viewers here follow worldwide trends. Extrapolating from Table 3 and 4 and taking into account the number of televisions in South Africa, Table 5 can be constructed.

It can be seen from Fig. 11 that the concentration of CRTs is still relatively high. This figure is bound to decrease as consumers opt to replace their aging TV sets with newer LCD or plasma models.

Conclusion

It has been demonstrated in this research that the range of power consumption per household, due to home entertainment devices, is in the range of 100 to 350 W. It was also shown that it is indeed possible to model accurately the behaviour of a combination of devices by using voltage and current measurements from individual devices.

The validity of the modelling method used was also tested, and found to be accurate.

Modelling of the harmonics of a home entertainment setup, using three different configurations, revealed overall power factors consistently above 0,9 in the on-mode which degraded to as low as 0,1 in standby mode.

The validity of the harmonic modelling method used was also tested and found to produce results very close to actual measurements. An increase in the harmonic content of home entertainment devices was observed during the standby mode. It is recommended that a further study be performed to determine the grid-wide effect of potentially millions of such devices producing harmonics during standby mode.

This paper was presented at the Domestic Use of Energy (DUE) conference at the Cape Peninsula University of Technology (CPUT) in April 2011

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